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PSIDD (II): A Prototype Post-Scan Interactive Data Display System for Detailed Analysis of Ultrasonic Scans

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ABSTRACT

This article presents the description of **PSIDD(II)**, a post-scan interactive data display system for ultrasonic contact scan and single measurement analysis. **PSIDD(II)** was developed in conjunction with ASTM standards for ultrasonic velocity and attenuation coefficient contact measurements. This system has been upgraded from its original version **PSIDD(I)** and improvements are described in this article. **PSIDD(II)** implements a comparison mode where the display of time domain waveforms and ultrasonic properties versus frequency can be shown for up to five scan points on one plot. This allows the rapid contrasting of sample areas exhibiting different ultrasonic properties as initially indicated by the ultrasonic contact scan image. This improvement plus additional features to be described in the article greatly facilitate material microstructural appraisal.

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I. Purpose of PSIDD System

A post-scan interactive data display system (**PSIDD(I)**[1] followed by **PSIDD(II)**) has been developed for viewing and comparing raw (digitized) data and resulting properties at multiple scan locations on any of the ultrasonic images formed from ultrasonic contact scans.[2] It is also used to view ultrasonic contact single measurement data. This system was developed in conjunction with ASTM standards for ultrasonic velocity and attenuation coefficient contact measurements[3,4] and will be publicly available as a pc/windows-based version **PSIDD(III)** for users of these standards.[5] (Modification of **PSIDD(III)** for a variety of data storage schemes will be possible.) **PSIDD(I)** was originally developed to 1) confirm the accuracy of images formed from ultrasonic contact measurements both from a software

signal processing and hardware performance standpoint and 2) interactively compare ultrasonic properties at different locations within samples. In contact measurements, two front surface and two back surface ultrasonic pulses obtained using the pulse-echo configuration are digitized and stored at every scan location. Subsequently, the pulses are fourier-transformed to the frequency domain and used in calculating ultrasonic reflection coefficient, attenuation coefficient, cross-correlation (pulse) velocity, and phase velocity (fig. 1).[2] Images of these ultrasonic properties are then formed at preselected frequencies if a contact scan, rather than a single measurement, has been performed. The ultrasonic contact scan method is especially sensitive for quantifying global variations (such as pore fraction variations) in microstructure as well as detecting isolated major material defects in monolithic[2] and composite materials.[6,7]

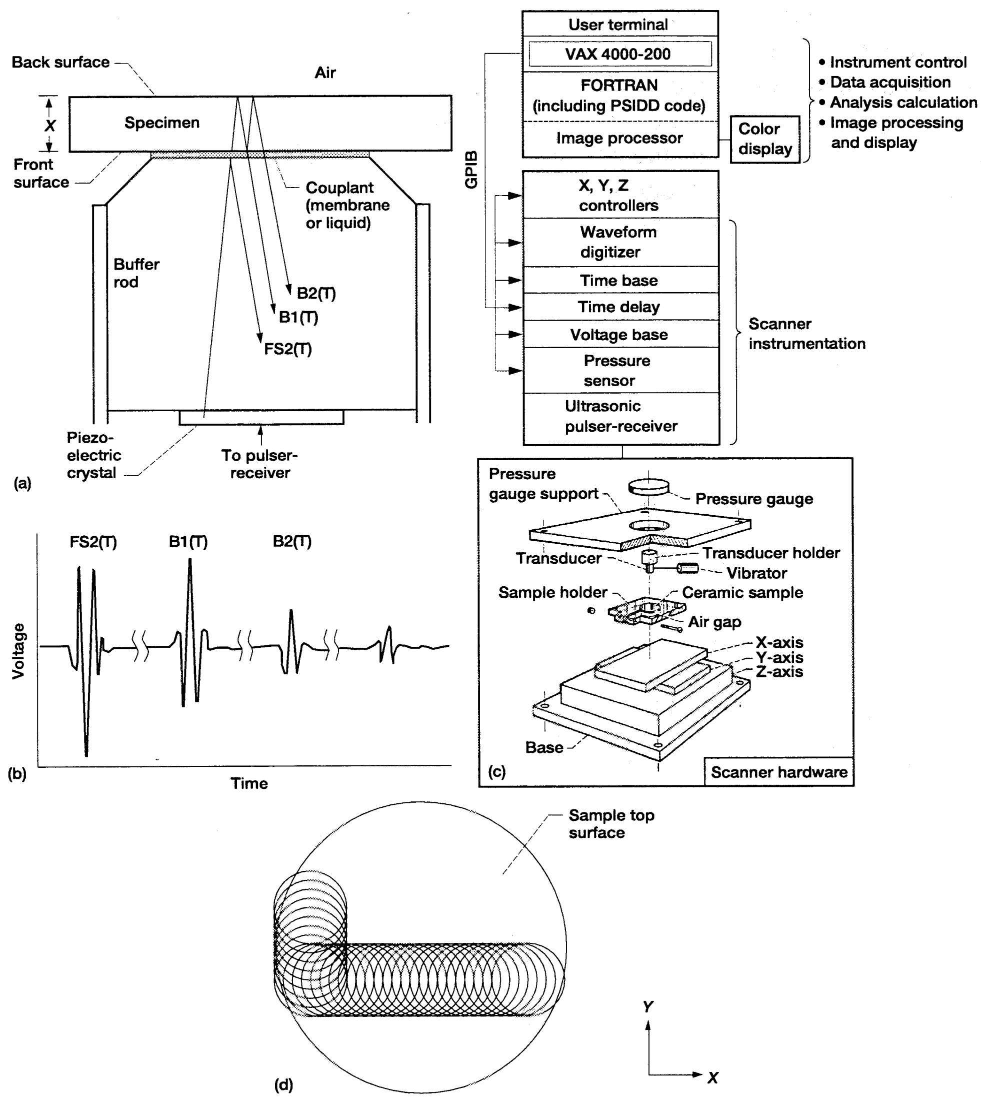


Figure 1.—Ultrasonic Measurement Method and Contact Scan System. (a) Diagram of buffer rod-couplant-sample pulse-echo contact configuration. FS2(T) = front surface reflection; B1(T) = first back-surface reflection; B2(T) = second back-surface reflection. FS1(T), not shown in this figure but shown in upcoming waveform displays, is acquired without sample or couplant on buffer rod. (b) Resulting waveforms for pulse-echo contact technique. (c) Computer-controlled ultrasonic contact scan system. (d) Schematic (top view) of ultrasonic contact scan procedure showing examples of successive transducer positions along X- and Y-dimensions of sample.

PSIDD (II) is a significant upgrade to the original version **PSIDD(I)** because it facilitates comparisons of waveforms and properties between sample regions exhibiting different ultrasonic behavior. A limitation of **PSIDD(I)** is that the plots of time domain waveforms and ultrasonic properties versus frequency contain information for only one scan point. Thus, although comparisons of ultrasonic properties at different scan locations are possible with **PSIDD(I)**, the comparisons are not optimized because they cannot be made on a single plot. **PSIDD(II)** implements a "comparison mode" where the display of time domain waveforms and ultrasonic properties versus frequency can be shown for up to five scan points on one plot. This feature allows the rapid contrasting of sample areas exhibiting different ultrasonic properties as initially indicated by the ultrasonic contact scan image, and is likely to aid in more accurate predictions of material behavior as compared to conventional ultrasonic c-scan testing where only waveform peak echo amplitude (and possibly time-of-flight) are mapped. The analysis provided by **PSIDD(II)** and **PSIDD(III)** can be the basis for artificial intelligence techniques that allow defect identification based on ultrasonic signatures (waveform shapes, and property versus frequency behavior).

II. System Overview

a. Hardware and Software

The **PSIDD(II)** system, like **PSIDD(I)**, uses a VAX 4000 - 200 computer running VAX/VMS A5.5-1 operating system interfaced to a Grinnell 274 image processing system via a DRV11 direct memory access board installed on the VAX's Q-bus. Two video displays are used (fig. 2a). A DEC VT340 terminal is the user terminal attached to the computer and a Mitsubishi 20LP is the video display monitor attached to the image processing system. A cursor control unit (CCU) is attached to the image processor and is shown in more detail in fig. 2b. High-level VAX FORTRAN software used for driving the system was written at Lewis Research Center. The Grinnell library of FORTRAN subroutines[8] is called from this high-level software. The user starts the **PSIDD(II)** program and is queried from the user terminal. The video display monitor shows ultrasonic images and the associated waveforms, spectra, and properties.

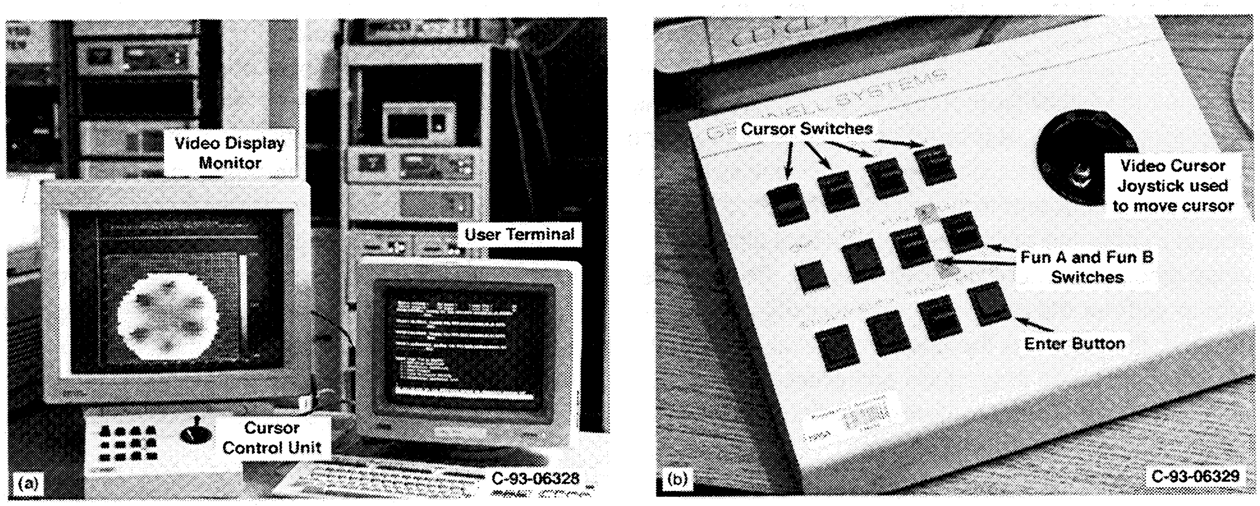


Figure 2. Video display setup for PSIDD operation. (a) computer user terminal, video display, and cursor control unit. (b) close-up of cursor control unit.

b. User Interface

The **PSIDD(II)** user interface consists of the VT340 user terminal, the 20LP video display, the cursor control unit (CCU), and the **PSIDD(II)** executable code. **PSIDD(II)** is started from the user terminal after logging into an account on the VAX. The user terminal is used to query the initial user options and display error messages. The video display monitor is used in conjunction with the CCU to display image and waveform information. Two different main display screens are shown on the video display during **PSIDD(II)** operation: the image display and the waveform displays. **Single point mode** is used when the user is interested in viewing waveforms and properties associated with a single scan point or single contact measurement. Multiple point **(Comparison)** mode is used when the user is interested in comparing waveforms and properties associated with up to five scan points. The image display is used to view the ultrasonic property images and to select scan locations where the user wishes to examine the digitized waveforms, spectra, and frequency-dependent property data. The waveform displays (**single point/comparison modes**) contain all of the time-domain and frequency-domain plots in various combinations based on user selection. All plots associated with a scan point can be viewed on a single screen if desired (complete waveform display). The movement of the CCU joystick and the positioning of the function switches on the CCU (fig. 2b) cause **PSIDD(II)** to switch among the display screens and perform different tasks depending on which screen is currently displayed on video.

c. Features For Application to Ultrasonic Contact Scan Images and Single Measurements

PSIDD(II) allows the display of any of the ultrasonic property images at predetermined frequencies generated from spectral analysis of ultrasonic contact scan data. These images include cross-correlation (pulse) velocity, phase velocity, reflection coefficient, attenuation coefficient, and attenuation coefficient error.[2] From a grid overlaying the image and representing the locations where ultrasonic data was obtained, and the use of the CCU, **PSIDD(II)** allows the operator to examine time-domain waveforms at any location where ultrasonic data was obtained. **PSIDD(II)** also allows the user to compare for up to five scan locations on one plot 1) time-domain waveforms, 2) frequency-domain magnitude and phase spectra of the waveforms, and 3) calculated ultrasonic material properties including phase velocity, reflection coefficient, attenuation coefficient, and attenuation coefficient error as a function of frequency. Digitized and calculated property data obtained from an ultrasonic contact scan and stored in files are retrieved via a direct access data retrieval algorithm which allows display of data. All of this information is displayed on the video display. For the frequency-domain transformed waveforms and frequency-dependent properties portions of the video display, the user can move the CCU over any waveform box to view on video in real-time specific values of waveforms and properties at any frequency within the broadband frequency regime realized during the ultrasonic contact scan. Waveforms are auto-scaled in both the horizontal and vertical directions and can be individually enlarged to take up the entire video display for more detailed viewing. The user can choose to view the two back surface waveforms with or without the ultrasonic system noise subtracted. Where interpolation of spectra and property data is needed, the user has the choice of linear or natural cubic spline interpolation. The - 6 dB bandwidth limits of ultrasonic pulse magnitude and phase frequency spectra can be displayed on the frequency-domain plots if desired. These features are also available for display of waveforms and spectra obtained from single contact measurement data.

III. Detailed Explanation of PSIDD(II) Operation and Features

a. Initial set-up and Queries

Before using **PSIDD(II)**, the user is first required to edit an initialization file (PSIDD.ini) that tells **PSIDD(II)** which file directory path the image and data files generated from the ultrasonic contact scan are

located in. The user then runs **PSIDD(II)** by typing "RUN PSIDD" at the DCL (Digital Command Language) prompt on the user terminal and is queried regarding data set prefix name (fig. 3a). In this example, a scanned silicon nitride ceramic sample having scan information stored in files with file name prefix SN2_CC_10 is confirmed and **PSIDD(II)** displays messages to the user terminal regarding the files read in associated with this prefix. Then the user is asked what specific image type and frequency is desired (fig. 3b). Here, as an example, phase velocity is chosen for the image type and 60 MHz is chosen for the frequency. The user is also asked which mode, **single point or comparison**, is desired. Following the initial queries, the image display is written to video.

```
DON_SPR>RUN PSIDD
%PSIDD-I_START, PSIDD starting...

%PSIDD-I_INIREAD, Reading initialization file PSIDD.INI
..............Done.

Prefix_name ?
SN2_CC_10

%PSIDD-I_DATASET, You will be working with the SN2_CC_10 datasets...
Do you wish to continue (y/n)?

Y

You can work on either single-point or multi-point (Comparison)
bases.
Single-point (S) or Multi-point (M)?

M

You are working on multi-point mode now.
Do you wish to continue (y/n)?

Y

How many points do you want to compare (2,3,4,5)?

3

GRINNELL IS AVAILABLE !
 Channel assigned =    160 status =     1 event flag =      63
 Channel assigned =    176 status =     1 event flag =      62

%PSIDD-I-SPCREAD, Reading the file DUC2:[ROTH.DATA]SN2_CC_10.SPCINFO
...............Done.
%PSIDD-I-CH_I2READ, Reading the file DUC2:[ROTH.DATA]SN2_CC_10.DATCH
...............Done.
%PSIDD-I-CH_I2READ, Reading the file DUC2:[ROTH.DATA]SN2_CC_10.DATI2
...............Done.
%PSIDD-I_ALLSHAPEREAD, Reading the file DUC2:[ROTH.DATA]SN2_CC_10.ALL
...............Done.

(a)
```

```
Select image file to
display:
  1 - Reflection
Coefficient
  2 - Attenuation
Coefficient
  3 - Phase Velocity
  4 - Cross Correlation
Velocity
  5 - Attenuation
Coefficient Error

3

Select image frequency:
        0 - 70 MHz
        1 - 40 MHz
        2 - 50 MHz
        3 - 60 MHz
        4 - 70 MHz
        5 - 80 MHz
        6 - 90 MHz
        7 - 100 MHz
        8 - 110 MHz
        9 - 120 MHz

3

(b)
```

Figure 3. Queries and messages to user terminal for PSIDD operation. (a) Initial query and messages. (b) Queries concerning image type and frequency.

Figs. 4a-g show the seven menus to be used in conjunction with the CCU for detailed operation of **PSIDD(II)**. The menus include the **Single Point Mode Image Display Menu, Single Point Mode Complete Waveform Display Menu, Single Point Mode Enlarged Graph Display Menu, Comparison Mode Image Display Menu, Comparison Mode Waveform Display Menu, Comparison Mode Enlarged Graph Display Menu,** and **Comparison Mode Waveform Display Submenu**, respectively. The CCU (fig. 2b) has 2 switches labeled "FUN A" and "FUN B." By moving the cursor control joystick,

toggling the FUN A and FUN B switches (down=0 and up=1), and subsequently pressing the ENTER button on the CCU, all of the options on the seven menus are accessed. (For the image processor setup used at Lewis Research Center, the cursor 1 switch on the CCU must be in the "up" position to allow cursor viewing.)

(a) Single Point Mode Image Display Menu.

FUN A	FUN B	**Action** to be performed when ENTER is pressed on the cursor control unit
0	0	If the cursor is on the image then display the waveform data corresponding to the cursor location on the image (and go to Single Point Mode Complete Waveform Display menu). If the cursor is off the image then toggle the image grid on and off.
0	1	Toggle the image display color scheme.
1	0	Toggle the display of highlighted (coded) data deemed significantly different from average on the image display.
1	1	Select a new image file to display

(b) Single Point Mode Complete Waveform Display Menu.

FUN A	FUN B	**Action** to be performed when ENTER is pressed on the cursor control unit
0	0	Return to the Image Display.
0	1	Toggle the screen color scale between gray and color.
1	0	If the cursor is on one of the two back surface waveforms (B1(t), B2(t)) then the noise subtraction option is toggled (waveform minus system noise is overlaid in red on top of waveform containing noise). If the cursor is on one of the spectra graphs then the -6 dB option is toggled.
1	1	Enlarge the individual graph box that the cursor is inside of.

(c) Single Point Mode Enlarged Graph Display Menu.

FUN A	FUN B	**Action** to be performed when ENTER is pressed on the cursor control unit
0	0	Return to Complete Waveform Display.
0	1	Toggle the screen color scale between gray and color.
1	0	If the cursor is on one of the two back surface waveforms (B1(t), B2(t)) then the noise subtraction option is toggled (waveform minus system noise is overlaid in red on top of waveform containing noise). If the cursor is on one of the spectra graphs then the -6 dB option is toggled.
1	1	Toggle between linear and spline interpolation for curves.

(d) Comparison Mode Image Display Menu.

***After the first point is selected and the waveform data is displayed, the user presses the Cursor Control Unit (CCU) ENTER button again which returns the image display to video for selection of the next scan point. This step is repeated until the total number of points originally chosen for property comparison are selected. The CCU ENTER button is then depressed again after all points have been chosen, and the comparison mode waveform display appears on video. This display first consists of a comparison of time-domain waveforms for the scan points selected and is called Screen A. The user then uses the Comparison menus shown in figs. 4e - g to obtain the further comparison displays desired.**

FUN A	FUN B	**Action** to be performed when ENTER is pressed on the cursor control unit
0	0	If the cursor is on the image then display the waveform data corresponding to the cursor location on the image.* If the cursor is off the image then toggle the image grid on and off.
0	1	Toggle the image display color scheme.
1	0	Toggle the display of highlighted (coded) data deemed significantly different from average on the image display
1	1	Select a new image file to display

Figure 4. PSIDD(II) Menus (used in conjunction with cursor control unit for selecting options in PSIDD(II)).

(e) Comparison Mode Waveform Display Menu.
***Screen A: FS1(T), FS2(T), B2(T) and B2(T) Amplitudes.**
Screen B: FS1(F) , FS2(F), B1(F) and B2(F) Magnitudes.
Screen C: Phase Differences between B1(F) and B2(F) for up to four points.
Screen D: Phase Velocity, Reflection Coefficient, Attenuation Coefficient and Attenuation Coefficient Error Spectra.

FUN A	**FUN B**	**Action** to be performed when ENTER is pressed on the cursor control unit
0	0	Return to the Image Display.
0	1	Toggle the screen color scale between gray and color.
1	0	Toggle between Screens A, B,C and D* when the cursor is on the Top Portion (note: cursor must be placed within one of the individual boxes in the display for toggling to occur). Erase / Add Points when the cursor is on the Bottom Portion (see figure 9)
1	1	Enlarge the individual graph box that the cursor is inside of.

(f) Comparison Mode Enlarged Graph Display Menu.

FUN A	**FUN B**	**Action** to be performed when ENTER is pressed on the cursor control unit
0	0	Return to Comparison Waveform Display Screen (A,B,C or D) where cursor call originated.
0	1	Toggle the screen color scale between gray and color.
1	0	Toggle between showing and not showing the -6 dB bandwidth lines when the cursor is on the Top portion. Erase / Add Points when the cursor is on the Bottom Portion (see figure 9)
1	1	Toggle between linear and spline interpolation for curves.

"Area" where the cursor is on	**Action** to be performed when cursor is placed on "Area" and ENTER is pressed on the Cursor Control Unit
Colorbar	Erase all the points
Point_1	Add Point One
Point_2	Add Point Two
Point_3	Add Point Three
Point_4	Add Point Four
Point_5	Add Point Five

(g) Comparison Mode Waveform Display Submenu. (Used for Waveform and Enlarged Graph Displays, when Fun A = 1 and Fun B = 0 and the cursor is on the bottom portion of the display (see figure 9), the Erase / Add Points option is Activated.)

Figure 4. PSIDD(II) Menus (used in conjunction with cursor control unit for selecting options in PSIDD(II)) (concluded).

b. Single Point Mode

i. Image Display

With, for example, the 60 MHz phase velocity ultrasonic image of the ceramic sample displayed on video, (initially written to video with a grid overlaying the image that represents the locations where ultrasonic data were obtained (fig. 5a)), the outlying black areas overlaid with the grid represent areas of the rectangular holder which contained the disk-shaped silicon nitride ceramic sample. The image of the sample indicates material gradients via gray scale variations. For the image display, the following four options exist as shown in the **Single point mode image display menu** (fig. 4a).

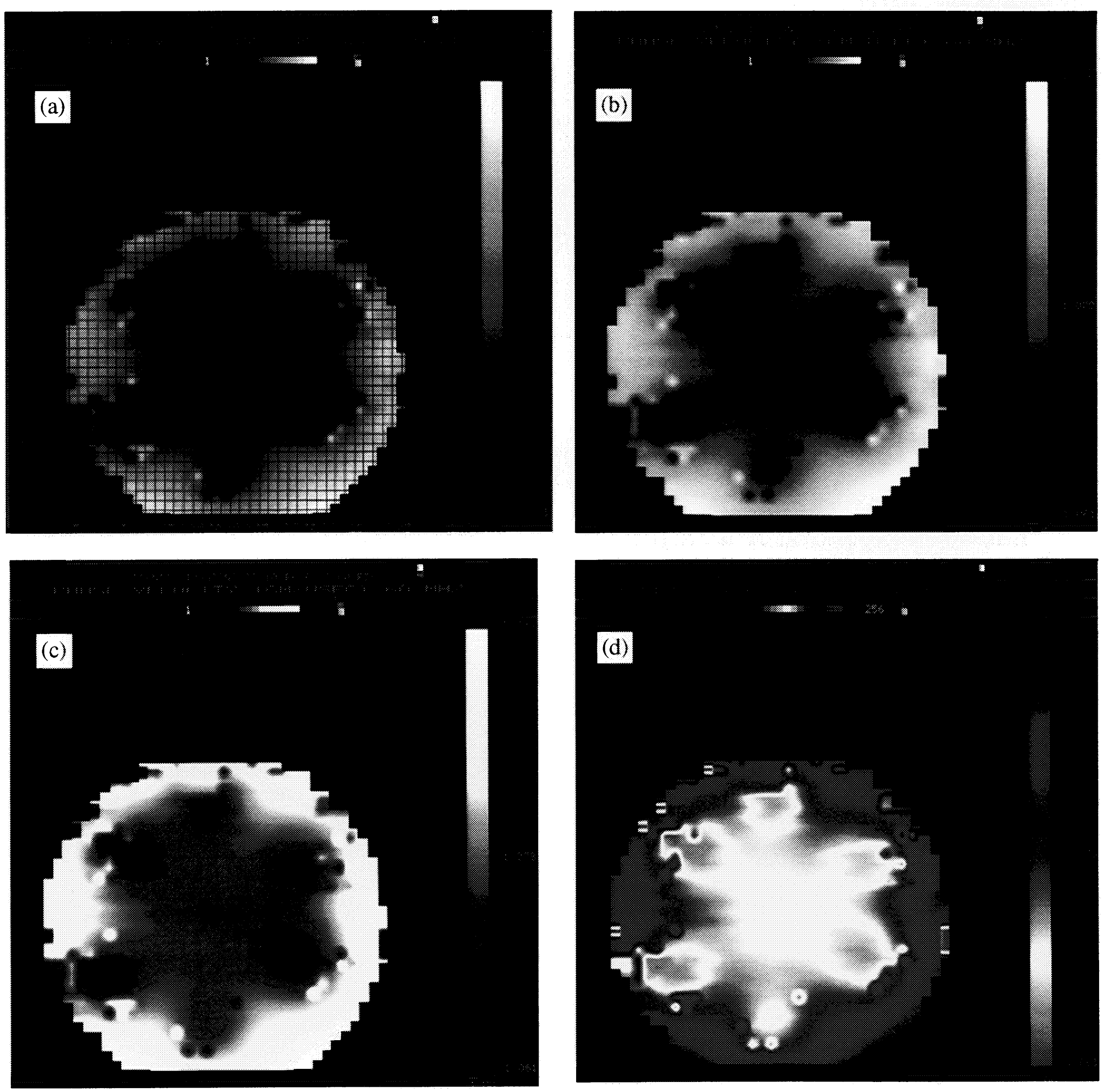


Figure 5. Single Point Mode Image Display: Initial Display for Ultrasonic image (Phase Velocity, 60 MHz) of silicon nitride disk. (a) With overlaid grid representing measurement locations. (b) Without grid. (c) With a different color scheme. (d) With another different color scheme.

With FUN A = 0 and FUN B = 0 on the CCU, and the cursor moved off the image of the part and placed on the outlying black areas beyond the grid, the overlaid grid can be toggled off (fig. 5b) and on (fig. 5a). A clearer view of the image can be seen with the grid turned off. With FUN A = 0 and FUN B = 1, the image color scheme can be varied from gray scale to a variety of different color schemes, two of which are shown in figs. 5c and d.

With FUN A = 1 and FUN B = 0, locations where ultrasonic scan data and resulting property values are deemed significantly different than average (from analysis performed after the contact scan) are highlighted as shown in fig. 6. Each different color and pattern scheme represents a different data condition and indicates what ultrasonic property might be affected. Codes BA, BC, BP and BV represent locations where attenuation coefficient, cross-correlation velocity, phase velocity, and both types of velocities, respectively, are significantly different than average. Code BE represents edge locations for a nonrectangular sample. Table 1 gives the criterion used for assigning these codes to a scan location. The highlighting allows the user to 1) go to highlighted locations for a closer examination of the digitized and processed data and 2) perform data filtering as needed to obtain a more accurate image if the data is deemed bad. With FUN A = 1 and FUN B = 1, the user terminal displays the queries shown in fig. 3b and the user has the opportunity to select a new image type.

Returning to the option where FUN A = 0 and FUN B = 0 and the video cursor moved to a specific scan location (x=11, y=12) (displayed in the upper right-hand corner of fig. 7a), the waveform data (complete waveform display) corresponding to the cursor location on the image is displayed on video (fig. 7b). While the video cursor is moved to a specific location on the image, a block composed of four color squares at the top right of the display shows rotating colors. When the video cursor is stationary, the colors stop rotating.

ii. Complete Waveform Display

The single-point mode complete waveform display shown in fig. 7b has 13 boxes of information associated with the scan point. The ultrasonic image is shown in the lower portion of the waveform display with a mark denoting the scan point location associated with the time domain waveforms and property versus frequency data shown. The top row of boxes show digitized time-domain ultrasonic waveform data from the pulse-echo ultrasonic contact measurement (fig. 1) at that location. In fig. 7b, the waveforms labeled FS1(T) and FS2(T) are the first front surface reflections without and with the sample present on the buffer rod, respectively, where T is time. The waveforms labeled B1(T) and B2(T) are the first and second ultrasonic pulses reflected off of the sample back surface. The delay times corresponding to the echo start relative to the main ultrasonic pulse are given at the top of the four boxes. The time and voltage scales of the waveforms are shown in the lower right and middle left of the boxes, respectively. The time scale is denoted by a scale marker and the voltage scale is given in volts (V)/division (D).

The middle 4 boxes of the waveform display in fig. 7b show ultrasonic properties as a function of frequency. The equations used to calculate frequency-dependent ultrasonic properties obtained from the pulse-echo configuration are given in the Appendix. The first box on the left shows the Fourier-transformed front surface reflections FS1(F) and FS2(F) magnitude spectra where F is frequency. The spectra are color-coded. Highest magnitude in volt-sec is shown at the upper left, and frequency scale (auto-scaled based on frequency extent of magnitude spectra) is shown at the middle right. The magnitudes at the selected image frequency of 60 MHz are pointed at with a dotted line and displayed for reference. The next 2 boxes to the immediate right show phase angle (θ) and magnitude spectras for Fourier-transformed back surface reflections B1(F) and B2(F). The lower left of the phase angle spectra box shows the lowest phase angle (referenced from $\theta = 0°$) in terms of number of 360° revolutions (RV) plus the number of degrees less than 360°. (Please note that the number of revolutions can be a function

of the signal processing routine's attempt to provide a continuous curve for phase angle vs. frequency.) A dotted line in the magnitude spectra box points to the ratio of the B1(F) and B2(F) magnitudes at the selected image frequency of 60 MHz. As before, highest magnitude in volt-sec is shown at the upper left of the magnitude spectra box and frequency scaling (which is the same as for the FS1(F)/FS2(F) box) is displayed at the middle right of both boxes. The next box to the right contains two graphs: the upper one contains phase velocity (cm/μsec) as a function of frequency while the lower one shows the ratio of phase velocity to cross-correlation velocity as a function of frequency. The next box to the right displays reflection coefficient as a function of frequency. As before, the magnitudes of the properties at the selected image frequency are pointed at with a dotted line and displayed.

The lowest set of boxes shows attenuation coefficient as a function of frequency (neper (NP)/cm (CM)) (left-most box), % error in the attenuation coefficient as a function of frequency (middle), and an information box (right-most box). The attenuation coefficient box shows color-coded error (± sigma) bands which were derived from the % error in the attenuation coefficient calculation (Appendix). The error bands and % error in attenuation coefficient are necessary to show what frequencies are most valid for the attenuation coefficient calculation. The information box displays the present date, sample name, sample thickness, scan position, nominal transducer center frequency, cross-correlation velocity, phase velocity at the selected image frequency, frequency range over which extreme-value data filtering / clipping was performed, and whether the scan location is "good" (G) or "potentially bad" (BA, BC, BP, BV or BE) where "potentially bad" refers to the questionable data previously discussed. At this point, movement of the video cursor into the time- and frequency-domain boxes on the waveform display allows the display of ultrasonic property values at any time or frequency location (within the broadband frequency regime realized during the ultrasonic contact scan) in the lower right corner of the information box (fig. 7c and d). In figs. 7c and d, phase velocity at 78 MHz and the amplitude of B2(T) at 4.036 μsec are displayed, respectively, by moving the video cursor into the appropriate boxes.

Another example of a complete waveform display is shown in fig. 7e for the scan location (x=10, y=13). This point has been coded BA (fig. 6), representing a condition where the attenuation coefficient is significantly different from the average seen for this sample. The code assignment to this point resulted from a double-peaked B2(F) magnitude spectra, the underlying cause of which is a highly-distorted B2(T). It is seen that, in addition to an attenuation coefficient significantly higher than that for the scan location (x=11, y=12) (fig. 7c), the slope of the attenuation coefficient versus frequency curve is greater than that for the latter scan location as well. In this case, the distortion in B2(T) is due to wave scattering caused by interaction with microstructure.[2] It is also possible that faulty data acquisition can result in an invalid waveform for property calculation.[1] With the complete waveform display on video, the following four options exist as shown in the **single-point mode complete waveform display menu** (fig. 4b). With FUN A = 0 and FUN B = 0, the user is returned to the image display. With FUN A = 0 and FUN B = 1, the waveform display can be toggled between color and gray scale schemes (fig. 7f). The gray scale scheme can be used if a gray scale printer is available or gray scale hardcopies are required. With FUN A = 1 and FUN B = 0, and the cursor located in one of the two back surface echo (B1(T) or B2(T)) boxes in the top row of boxes, the specific B1(T) and B2(T) waveforms can be displayed without and with the system noise subtracted (the latter is overlaid in red on top of the former) (fig. 7g). (Noise at the time delays where the back surface echoes were located was digitized and stored before the couplant and sample were placed on the ultrasonic transducer, hence it is called "system noise.") The information box will note if the waveform with noise subtracted is overlaid onto the waveform without noise subtracted. With FUN A = 1 and FUN B = 0, and the cursor located in one of the ultrasonic property versus frequency boxes, vertical lines demarcating the "average" - 6 dB frequency bounds (i.e, 50% magnitude bandwidth) calculated from the average of those for FS1(F), FS2(F), B1(F) and B2(F) spectra are displayed in all of the property versus frequency boxes (fig. 7h). The 50% bandwidth is generally considered the most valid region of ultrasonic data due to relatively high signal-to-noise ratio (SNR). The information box will note if

the - 6 dB bounds are displayed. With FUN A = 1 and FUN B = 1, the phase velocity versus frequency box can now be enlarged (enlarged graph display) for a closer examination if necessary (fig. 7i).

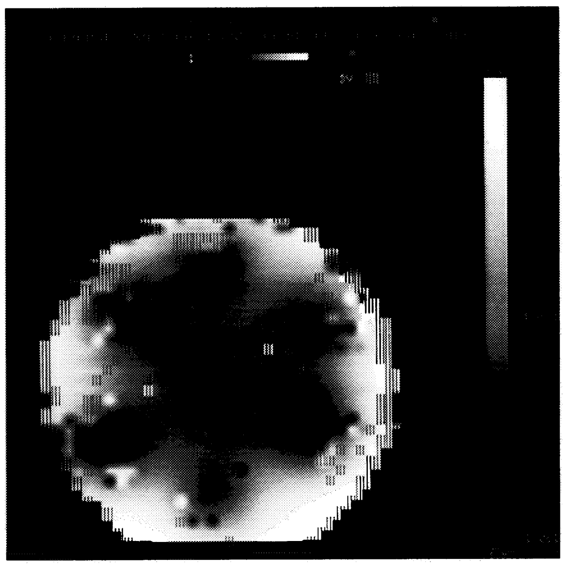


Figure 6. Single Point Mode Image Display: Ultrasonic image (Phase Velocity, 60 MHz) of silicon nitride disk with highlighted scan locations representing locations where ultrasonic properties are significantly different than average based on criterion of Table I.

Table I. Criteria for "Coding" Locations in Ultrasonic Contact Scan Images

CODE AND DEFINITION	CONDITION(S)
BA - attenuation coefficient value significantly different than average	1. Reflection coefficient at transducer center frequency is above or below user-specified limits.[a] 2. Attenuation coefficient at transducer center frequency is above or below user specified limits. 3. Fourier magnitude spectra of second back surface pulse B2(F) exhibits "significant" double-peak characteristic.
BC[b] - cross-correlation velocity value significantly different than average	Cross-correlation velocity is above or below user-specified limits.
BE[b,c] - data at edge locations	The first and last two locations in a scan row for irregularly-shaped (egs. circular) sample.
BP[b] - phase velocity values significantly different than average	Phase velocity at transducer center frequency is above or below user-specified limits.
BV[b] - cross-correlation and phase velocity data significantly different than average	First back surface pulse B1(T) is improperly digitized at a lower amplitude setting than for the second back surface pulse B2(T).

[a]a reflection coefficient significantly different than average will lead to an attenuation coefficient significantly different than average.

[b]Points coded BC, BP, BV, or BE are implied to also be coded BA since any highly-distorted waveform of the three acquired at a scan location will affect the attenuation coefficient calculation.

[c]When the ultrasonic transducer is located at the interface between the edges of an irregularly-shaped sample such as a circular puck and the sample holder during an ultrasonic contact scan, scattering effects may take place making the waveforms highly distorted.

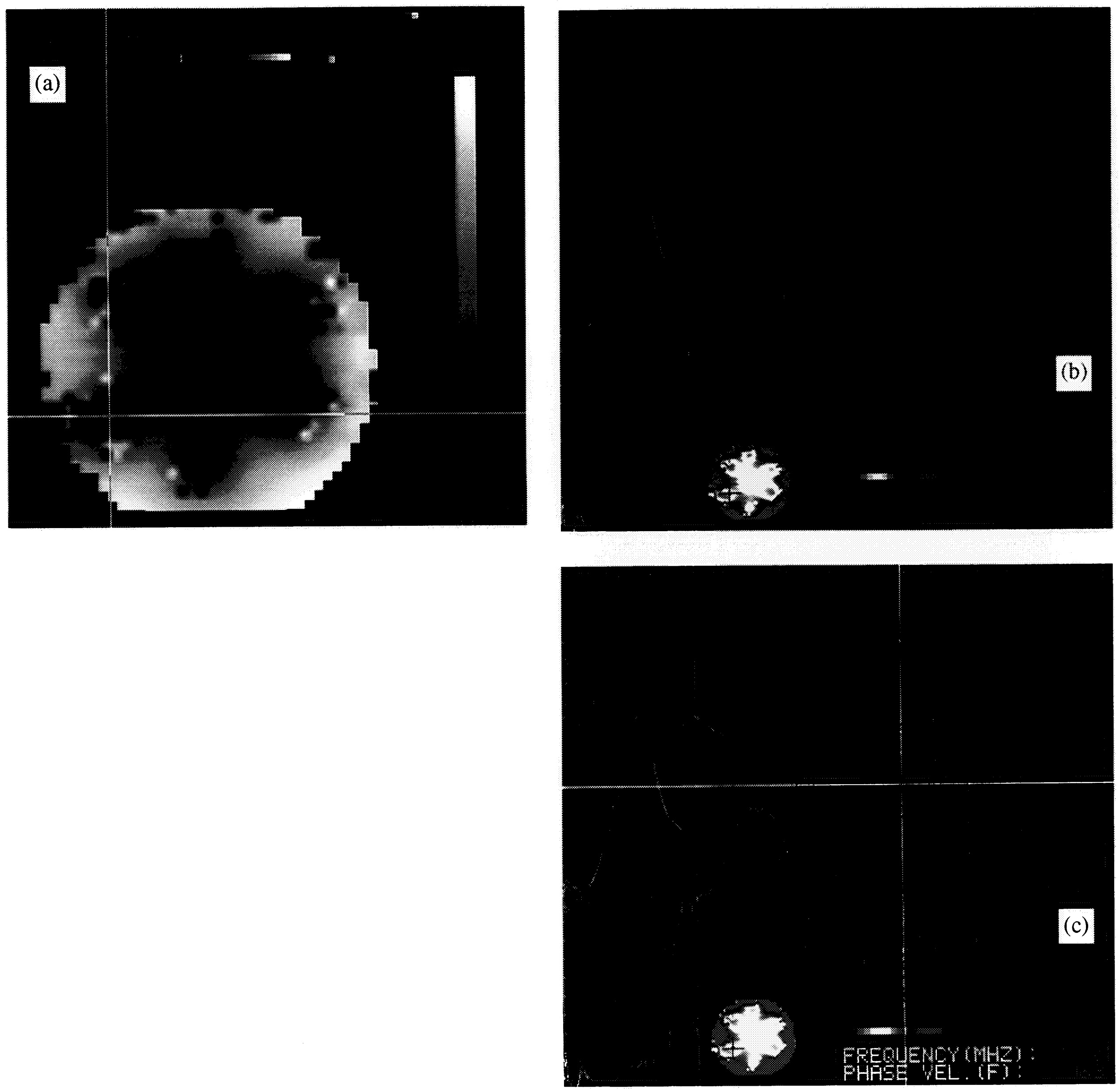


Figure 7. Single Point Mode Image and Waveform Displays for several locations shown in Ultrasonic image (Phase Velocity, 60 MHz) of silicon nitride disk. (a) Video cursor moved to a specific scan location (x=11, y=12). (b) Complete waveform display at scan location (x=11, y=12). (c) Phase velocity at 78 MHz is displayed by moving the video cursor in the phase velocity versus frequency graph boxes. (d) Amplitude of B2(T) at 4.036 :sec is displayed by moving the video cursor in the B2(T) box. (e) Complete waveform display for scan location (x=10, y=13) which was coded BA (see table I). (f) Complete waveform display shown in gray scale. (g) Complete waveform display shown with B1(T) and B2(T) waveforms with system noise overlaid in RED color on top of same waveforms without system noise. (h) Complete waveform display with - 6 dB frequency bounds shown on ultrasonic property versus frequency graph boxes. (i) Enlarged graph display of phase velocity versus frequency.

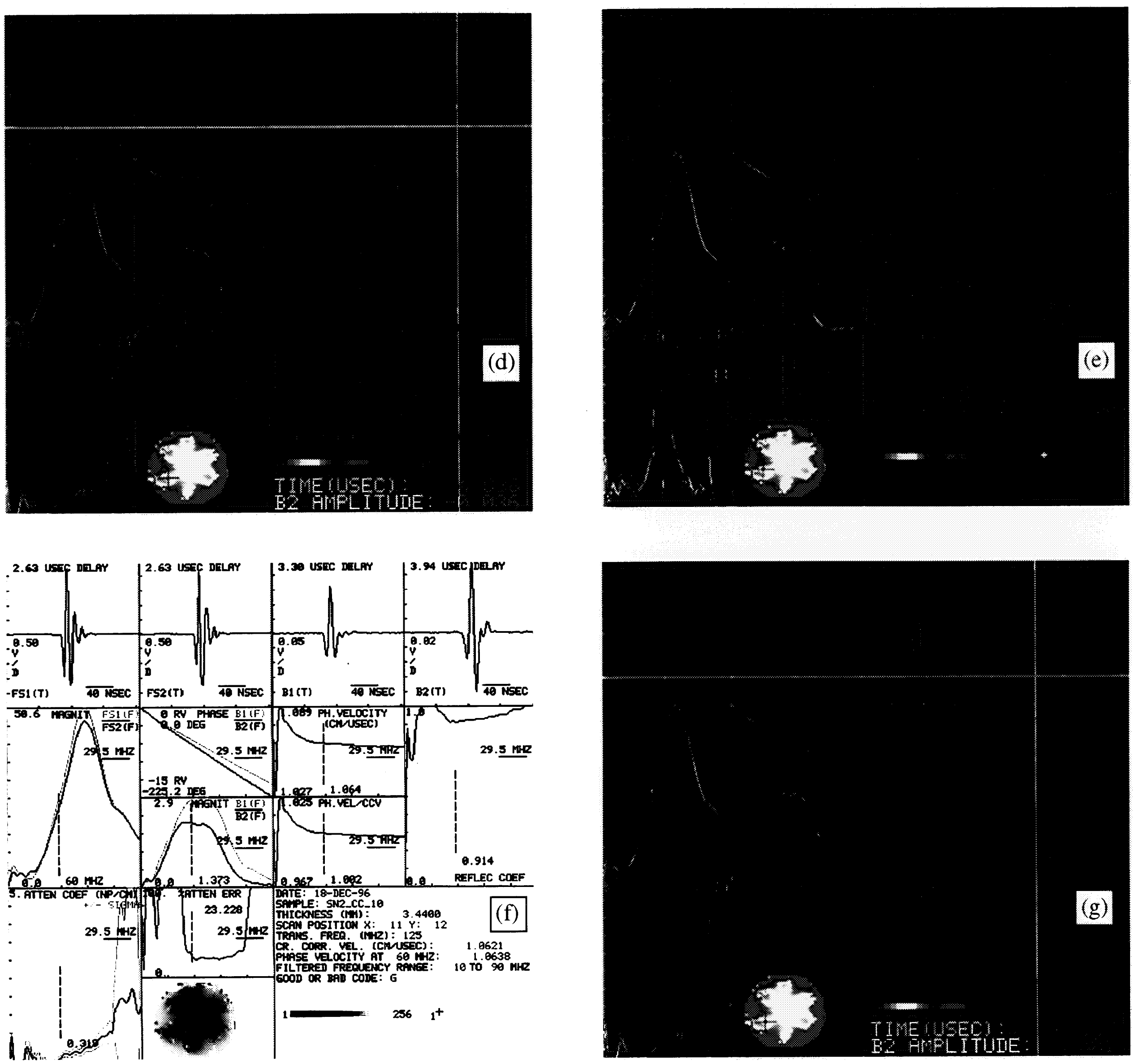
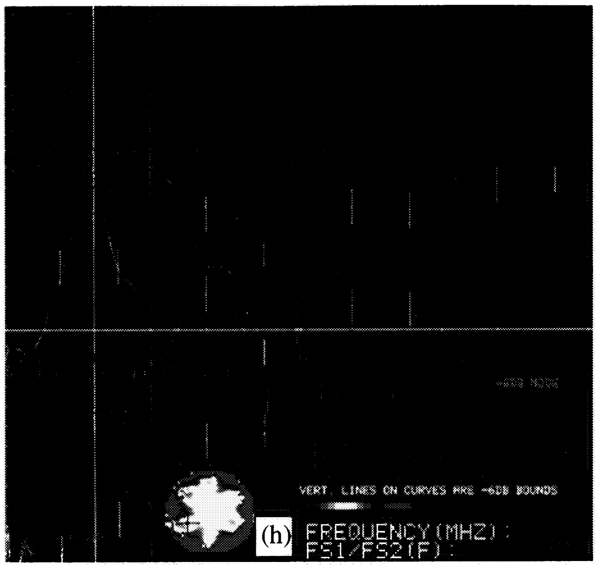


Figure 7. Single Point Mode Image and Waveform Displays for several locations shown in Ultrasonic image (Phase Velocity, 60 MHz) of silicon nitride disk (continued).



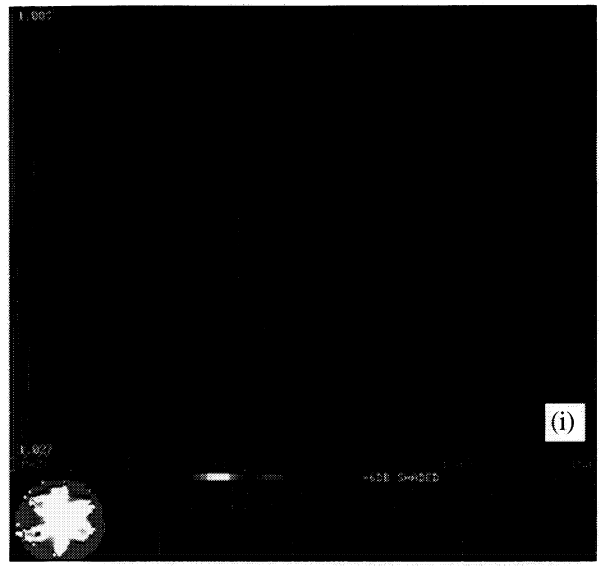


Figure 7. Single Point Mode Image and Waveform Displays for several locations shown in Ultrasonic image (Phase Velocity, 60 MHz) of silicon nitride disk (concluded).

iii. Enlarged Graph Display

The **single-point enlarged graph display menu** is shown in fig. 4c. The single-point enlarged graph display mode allows more detailed examination of waveforms and frequency-dependent properties. Menu options, and use of the cursor to get property values at specific time and frequency locations, are similar to those described previously for the complete waveform display. Additionally, the curves can be displayed with spline or linear interpolation (FUN A = 1 and FUN B = 1). The - 6 dB option when toggled on now shows regions outside of the - 6 dB frequency bounds as shaded.

b. **Comparison Mode**

i. Image Display

Fig. 4d shows the **comparison mode image display menu**. (The options corresponding to FUN A = 0 and FUN B = 1, FUN A = 1 and FUN B = 0, and FUN A = 1 and FUN B = 1 are the same as those shown in the single point mode image display menu shown in fig. 4a). Operation in comparison mode requires FUN A = 0 and FUN B = 0 on the cursor control unit (CCU). After the first point is selected on the image display and the waveform data is shown, the user presses the CCU ENTER button again which returns the image display to video for selection of the next scan point. This step is repeated until the total number of points originally chosen for property comparison are selected. Fig. 8a shows the image display with two scan points chosen for comparison of properties. (Up to five scan points can be displayed in comparison.) The CCU ENTER button is then depressed again after all points have been chosen, and the comparison mode waveform display appears on video. Status and confirmation messages are shown on the VT340 user terminal during this procedure so that if the user wishes to discard points and choose again, he or she can do this. The initial comparison mode waveform display first consists of a comparison of time-domain waveforms for the scan points selected and is called Comparison Screen A (fig. 8b). The user then uses the comparison menus shown in figs. 4d - g to obtain the further comparison displays desired.

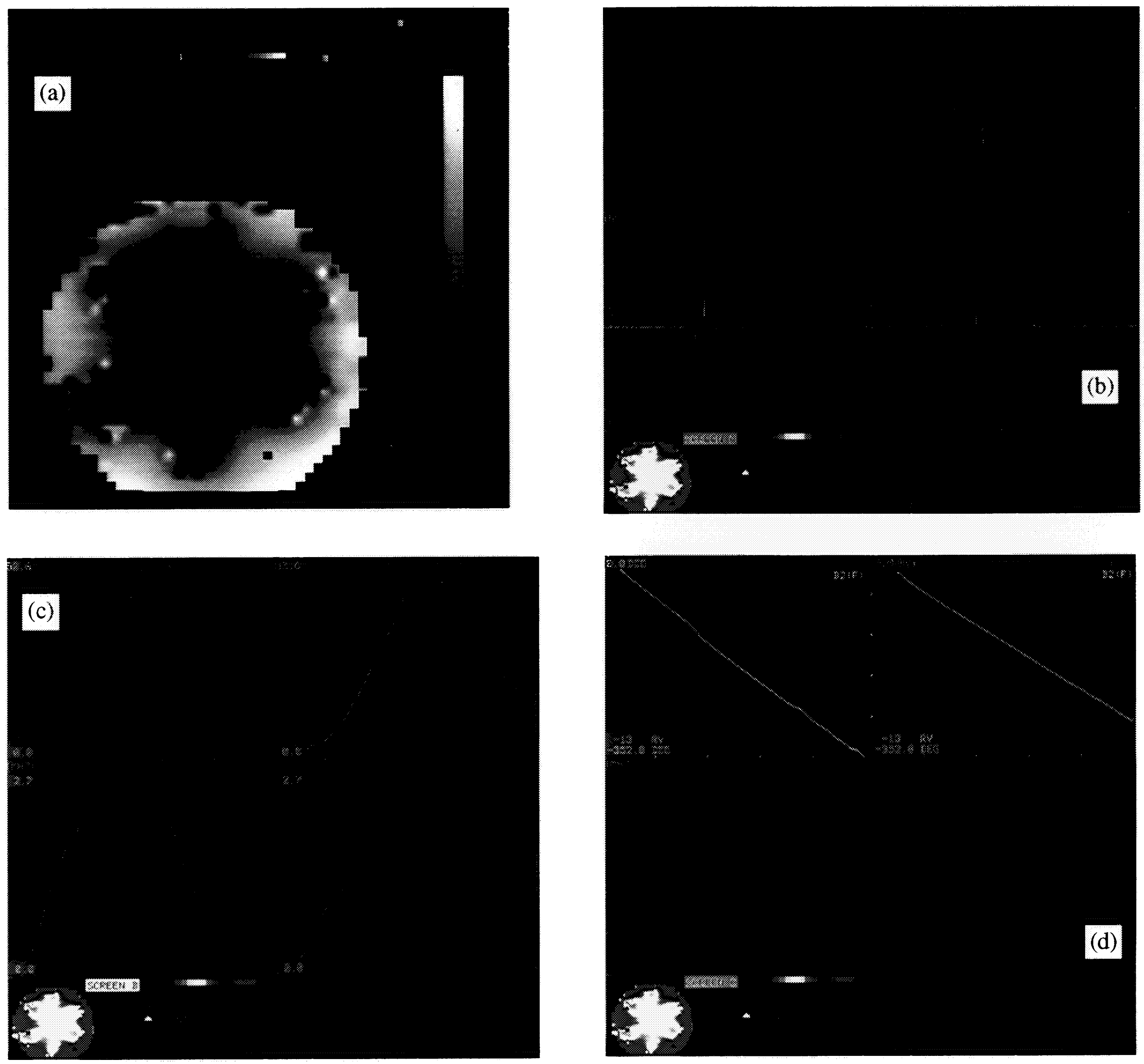
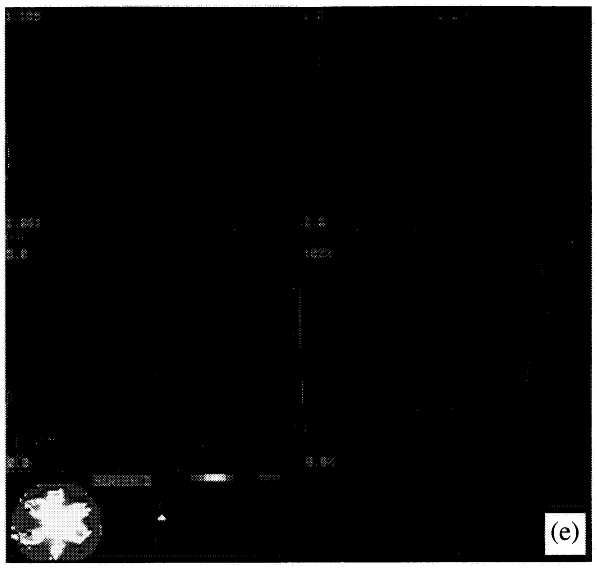


Figure 8. Comparison Mode Image and Waveform Displays for two scan locations shown in Ultrasonic image (Phase Velocity, 60 MHz) of silicon nitride disk. (a) Image Display showing two scan locations (x=9, y=13 and x=29, y=6) chosen for comparison. (b) Waveform display Screen A showing comparisons of time domain waveforms. (c) Waveform display Screen B showing comparisons of frequency domain magnitude spectra. (d) Waveform display Screen C showing comparisons of frequency domain phase spectra. (e) Waveform display Screen D showing comparisons of ultrasonic properties versus frequency curves (phase velocity, reflection coefficient, attenuation coefficient and attenuation coefficient error versus frequency). (f) Phase velocity at 65 MHz is displayed for both scan locations by moving the video cursor in the phase velocity versus frequency graph box of Waveform display Screen D.



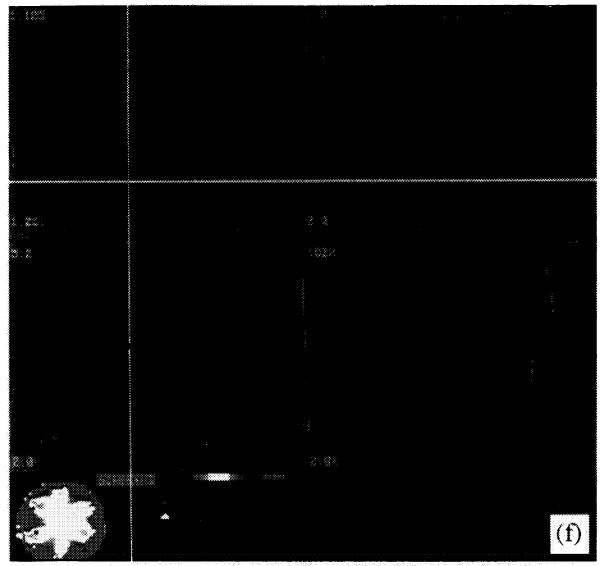


Figure 8. Comparison Mode Image and Waveform Displays for two scan locations shown in Ultrasonic image (Phase Velocity, 60 MHz) of silicon nitride disk (concluded).

ii. Waveform Display

The comparison mode waveform display has four screens associated with it for which time- and frequency-domain properties for up to five scan points can be displayed in comparison. For the two scan points chosen as shown in fig. 8a, comparison screens A (fig. 8b), B (fig. 8c), C (fig. 8d), and D (fig. 8e) show in comparison the time domain waveforms, fourier-transformed magnitude waveforms, phase differences between B1(F) and B2(F), and property versus frequency spectra, respectively. The ultrasonic image is shown in the lower portion of the waveform display with marks denoting the scan point locations associated with the time domain waveforms or property versus frequency data displayed. In the waveform displays, movement of the video cursor allows the display of ultrasonic property values at any time position or frequency (within the broadband frequency regime realized during the ultrasonic contact scan) for the selected points in the lower right corner of the screen (fig. 8f).

The following options are possible using the **comparison mode waveform display menu** (fig. 4e). With FUN A = 0 and FUN B = 0, the user is returned to the image display. With FUN A = 0 and FUN B = 1, the waveform display can be toggled between color and gray scale schemes. With FUN A = 1 and FUN B = 0, and the cursor placed in one of the plot boxes, the screen is toggled between screens A, B, C and D. With FUN A = 1 and FUN B = 1, the one particular waveform display in any of screens A, B, C, or D within which the cursor lies can now be enlarged to full screen for a closer comparison of curves.

With FUN A = 1 and FUN B = 0, the user also has the ability to erase and add curves depending on the position of the cursor. The user is referred to the **comparison mode waveform display submenu** (fig. 4f). For example, with the cursor placed on the colorbar (fig. 9a), all curves are erased (fig. 9b). Then, by placing the cursor on "Point_" text (fig. 9c), curves can be individually added (fig. 9d). This feature is useful when, for example, five points' curves are being compared initially and then one decides it would be valuable to immediately compare only two of the five points' curves.

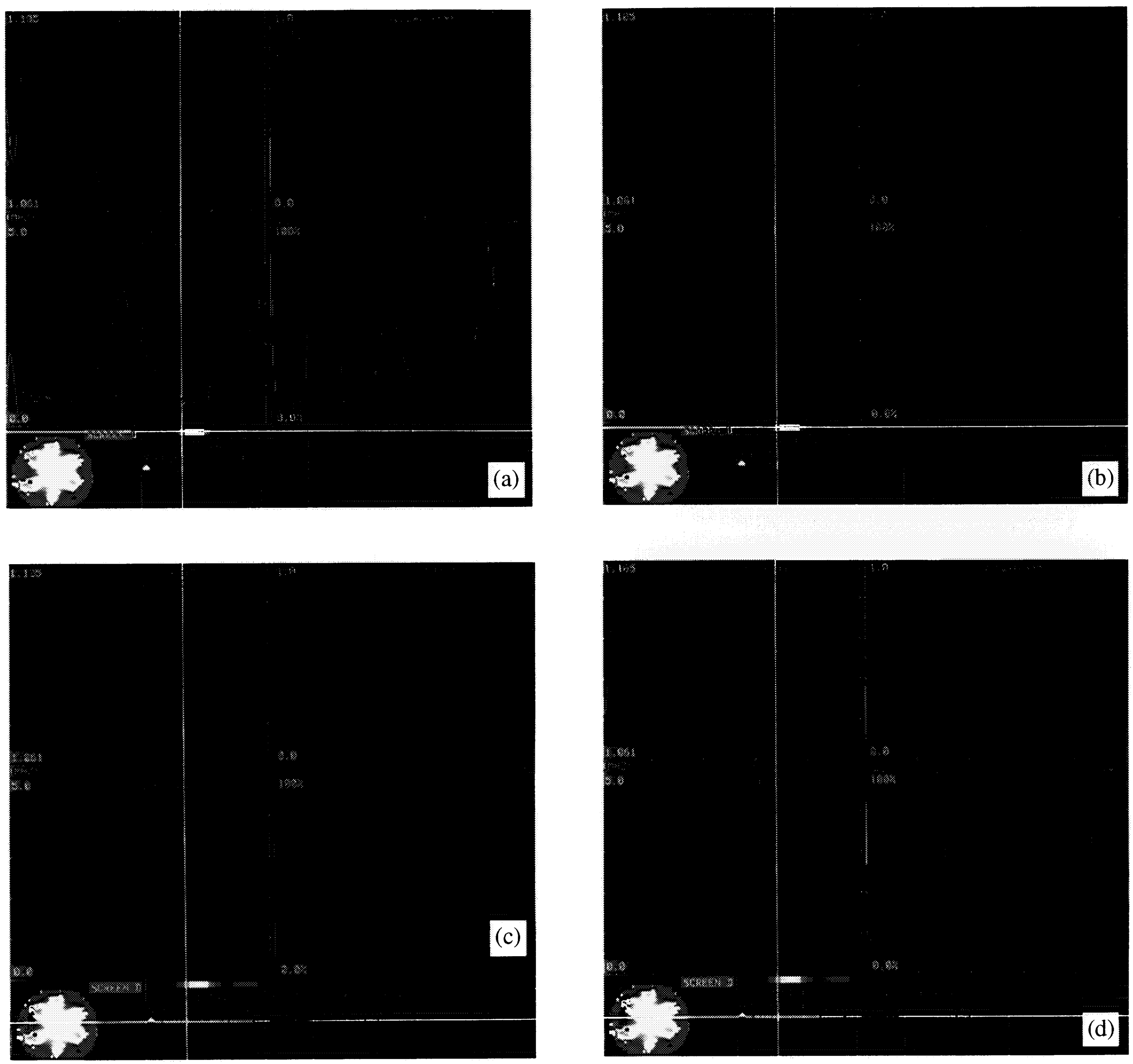


Figure 9. The ability to erase and add curves in Comparison Mode Waveform Displays. (a) Placing cursor on color bar and hitting CCU enter results in: (b) erasing all curves, (c) Placing cursor on "Point_2" text and hitting CCU enter results in: (d) redisplay of curves associated with second scan location chosen for comparison.

iii. Enlarged Graph Display

The **comparison mode enlarged graph display menu** is shown in fig. 4g. The comparison mode enlarged graph display is similar to the single-point enlarged graph display; it allows more detailed examination and **comparisons** of time-domain waveforms and frequency-dependent properties. Menu

options, and use of the cursor to get property values at specific time and frequency locations, are similar to those described previously for the comparison mode waveform display. Additionally, the curves can be displayed with spline or linear interpolation (FUN A = 1 and FUN B = 1). The - 6 dB option when toggled on shows regions outside of the - 6 dB frequency bounds as shaded. With FUN A = 1 and FUN B = 0, the user can erase or add curves exactly as described previously for the comparison mode waveform display.

IV. Conclusion

This article presents a user manual for, and description of, **PSIDD(II)**, a post-scan interactive data display system for analysis of data from ultrasonic contact measurements, either from scans or single locations. The **PSIDD(I)** system was originally developed to allow users to interactively examine digitized and processed information for multiple scan locations of an ultrasonic contact scan. The **PSIDD(II)** system is a significant upgrade to **PSIDD(I)** because the latter version was not developed with multiple scan point property comparisons as the primary goal. Although comparisons of ultrasonic properties at different scan locations are possible with **PSIDD(I)**, the comparisons are not optimized because they cannot be made on a single plot. **PSIDD(II)** implements a comparison mode where the display of time domain waveforms and ultrasonic properties versus frequency can be shown for up to five scan points on one plot. This allows the rapid contrasting of sample areas exhibiting different ultrasonic properties as initially indicated by the ultrasonic contact scan image. This information is displayed on a video display monitor and includes acquired time-domain waveforms, frequency-domain magnitude and phase spectra, and ultrasonic properties (pulse velocity, phase velocity, reflection coefficient, attenuation coefficient, attenuation coefficient error) as a function of frequency for a material. **PSIDD(II)** was developed in conjunction with ASTM standards for ultrasonic velocity and attenuation coefficient contact measurements and will be publicly available as a pc/windows-based version **PSIDD(III)** for users of these standards. It is believed that this system can serve as a component of an artificial intelligence system for automatic defect classification based on wave shape and ultrasonic property versus frequency characteristics.

V. Appendix: Equations Used to Calculate Ultrasonic Properties

The following equations are valid for the pulse-echo configuration (fig. 1). Cross-correlation velocity is calculated from[9]

$$V = 2\frac{X}{\tau_o} \tag{1}$$

where τ_o is the time shift for which

$$\left| \lim_{T\to\infty} \int_{-T}^{T} B_1(t) \circ B_2(t+\tau) \right| \infty \leq \tau \leq \infty \tag{2}$$

reaches a maximum value and X is sample thickness.

Ultrasonic reflection coefficient is calculated according to[2]

$$|R(f)| = \frac{|FS_2(f)|}{|FS_1(f)|} \tag{3}$$

where f is frequency, $|FS_1(f)|$ and $|FS_2(f)|$ are the Fourier magnitude spectra of the time domain pulses $FS_1(t)$ and $FS_2(t)$ without and with the sample present on the buffer rod, respectively.

Attenuation coefficient is calculated according to[2]

$$\alpha(f) = \frac{1}{2X} \ln \frac{|B_1(f)||R(f)|}{|B_2(f)|} \tag{4}$$

where $|B_1(f)|$ and $|B_2(f)|$ are the Fourier magnitude spectra of time-domain pulses $B_1(t)$ and $B_2(t)$, respectively. Percent error in the attenuation coefficient is calculated according to[2]

$$\% ERR_\alpha = (\frac{\sigma_\alpha}{\alpha})100 = 100(\frac{1}{2X\alpha})(\frac{1}{SNR})* \\ [(\frac{(\exp(4X\alpha))(R^2 + \exp(4X\alpha))}{(1 - R^2)^2} + 1)(\frac{1}{R^2}) \\ + 1 + (SNR^2)(4\alpha^2)(\sigma_X^2)]^{0.5} \tag{5}$$

where σ_α is the error in the attenuation coefficient measurement, X is sample thickness, σ_X is the error in the thickness measurement, R is reflection coefficient, and SNR is signal-to-noise ratio.

Phase velocity is calculated according to[10]

$$V(f) = \frac{(2X)2\pi f}{\Delta\theta}, \Delta\theta = \theta_1 - \theta_2 \tag{6}$$

where

$$\theta_1(f) = \tan^{-1} \frac{Im(B_1(f))}{Re(B_1(f))} \tag{7}$$

and

$$\theta_2(f) = \tan^{-1} \frac{Im(B_2(f))}{Re(B_2(f))} \tag{8}$$

where f is frequency, and $B_1(f)$ and $B_2(f)$ are the Fourier transformations of time domain pulses $B_1(t)$ and $B_2(t)$, respectively.

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13. ABSTRACT *(Maximum 200 words)*

This article presents the user manual for, and description of, PSIDD (II), a post-scan interactive data display system for ultrasonic contact scan and single measurement analysis. PSIDD (II) was developed in conjunction with ASTM standards for ultrasonic velocity and attenuation coefficient contact measurements. This system has been upgraded from its original version PSIDD (I) and improvements are described in this article. PSIDD (II) implements a comparison mode where the display of time domain waveforms and ultrasonic properties versus frequency can be shown for up to five scan points on one plot. This allows the rapid contrasting of sample areas exhibiting different ultrasonic properties as initially indicated by the ultrasonic contact scan image. This improvement plus additional features to be described in the article greatly facilitate material microstructural appraisal.

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